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Space Object and Light Attribute Rendering (SOLAR) Projection System

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A state of the art planetarium style projection system called Space Object and Light Attribute Rendering (SOLAR) Projection System was developed under the auspices of the DURIP program. The developed system integrates a commercial off the shelf (COTS) Digitarium Zeta Projection system with a high frame rate camera system to realize a hardware in the loop emulation system for imaging space objects. Separate software solutions were implemented to model the light transport processes involved in the imaging process. A fiberglass dome system was erected to make the SOLAR system a self contained facility. Calibration process was carried out to register the camera in the workspace of the projection system. The nationally unique SOLAR projection facility continues to support basic research activities involving photometric stereopsis, shape estimation and sensor tasking activities from represented images.

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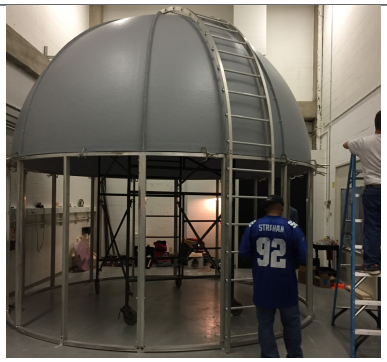
Space Object and Light Attribute Rendering (SOLAR) Projection System

1 Abstract

A state of the art planetarium style projection system called Space Object and Light Attribute Rendering (SOLAR) Projection System was developed under the auspices of the DURIP program. The developed system integrates a commercial off the shelf (COTS) Digitarium Zeta Projection system with a high frame rate camera system to realize a hardware in the loop emulation system for imaging space objects. Separate software solutions were implemented to model the light transport processes involved in the imaging process. A fiberglass dome system was erected to make the SOLAR system a self contained facility. Calibration process was carried out to register the camera in the workspace of the projection system. The nationally unique SOLAR projection facility continues to support basic research activities involving photometric stereopsis, shape estimation and sensor tasking activities from represented images.

2 Budget

We procured the following hardware (excluding miscellaneous items that were procured to support the installation process). Please see the Fiscal Report (FR) for further details.

Product	Image	Description & Justification	Cost ($)
Digitarium Zeta Projection System with Dome		The Zeta projection system is a high resolution (1200 px. diameter), 175 ^{o} FOV immersive visualization engine that can simulate a variety of beginner, advanced and programmable astronomical scenes for education, research and training. In addition to being compact, the projector is based on the Digital Light Processing (DLP) technology enabling a breath-taking detail, high frame rate (upto 120 Hz) and elaborate color in emulating space scenes. In-built high performance digitarium server can be interfaced with an external computer to display user defined imagery.	cf. FR
Installation of the projection system dome		The dome of the projection system was installed	cf. FR
		Estimated Total Cost	cf. FR

Collectively, the above equipment provided the basis for the installation of a world-class planetarium style projection system for emulation of a variety of close proximity and long range imaging experiments. University at Buffalo's Space Object and Light Attribute Rendering (SOLAR) projection system is a unique alternative for calibration and ground based testing of a variety of optical systems operating in the visual spectrum. It is a cost effective way to rapidly validate algorithms and imaging systems and establishes a systematic approach for hardware-in-the loop testing of vision based guidance, navigation, sensor tasking and control algorithms.

3 Supporting Information

The specific hardware requested directly impacts broad based missions of the Department of Defense (DoD), including:

- Sensor management, scheduling, space object data association and uncertainty quantification.
- Resident Space Object (RSO) characterization, attribute estimation and threat assessment of vital importance in Space Situational Awareness (SSA) activities.
- Spacecraft proximity operations, including but not limited to debris threat assessment, rendezvous and docking, refueling and repair activities.

In addition to the above mentioned research foci, the SOLAR projection system has spill-over applications in validation of Unmanned Vehicle simultaneous location and mapping, vision based auto-landing, target tracking and other applications of interest to the Department of Homeland Security and the Intelligence Community. SOLAR projection system provides the cornerstone for a unique opportunity that integrates the researchers at the University at Buffalo (UB) with competent undergraduate and graduate students to build a world-class center for validation and testing of optical systems in general and a focal point for SSA research activities in particular. We now provide some details pertaining to the research products that were significantly advanced by the DURIP investment.

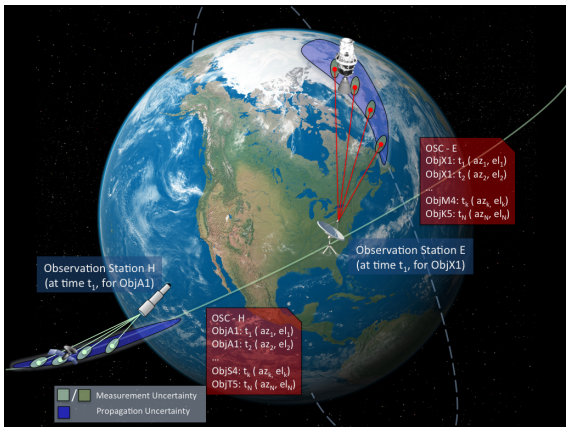


Figure 1: A schematic depicting sensor tasking and management operations

4 Specific Research Products

The following specific research products were supported by the DURIP instituted SOLAR projection system.

- Xue Iuan Wong, Manoranjan Majji, "An efficient method for klt-tracker uncertainty quantification and its application. Image and vision computing", submitted to Image and Vision Computing,
- X. Wong, M. Majji and P. Singla, "Photometric Method for 3D Reconstruction of Space Objects," accepted for publication, Chapter 12, Dynamic Data Driven Application Systems (DDDAS), Springer, 2017.
- X. Wong, M. Majji and P. Singla, "Applications of Photometric Stereopsis for Shape Estimation of RSOs", submitted for possible presentation at the 2017 AMOS Conference, August, 2017.
- X. Wong, "A Study of Photometry and Image Formation for Localization and Mapping Applications," PhD Dissertation, University at Buffalo, SUNY, December, 2016.

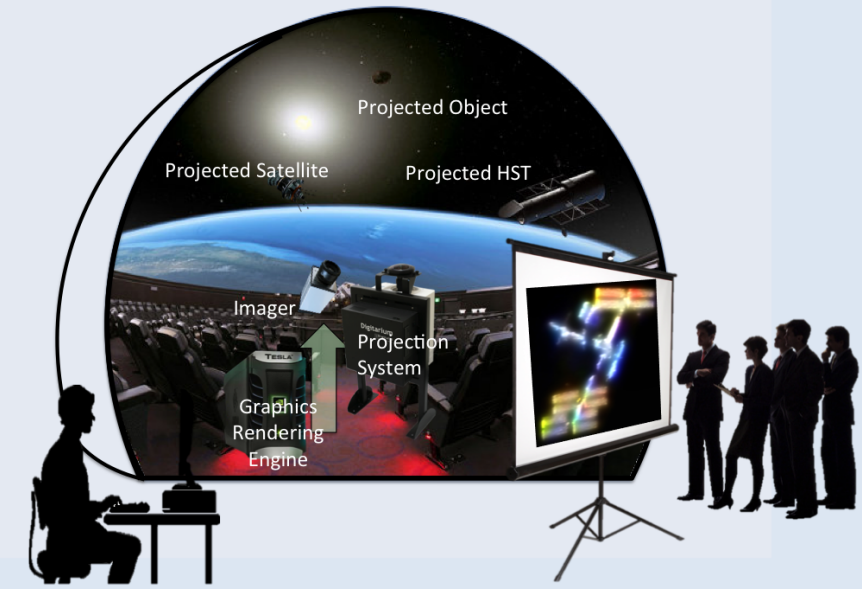


Figure 2: Schematic depicting the proposed SOLAR projection system

4.1 SOLAR Projection System

Faculty PIs and students at the University at Buffalo (UB) developed a unique planetarium style emulation system called the Space Object and Light Attribute Rendering (SOLAR) Projection System. On-orbit dynamics and control with sensor hardware in the loop can be simulated using the high fidelity dynamical system models of relative motion in the SOLAR system.

Fig. 2 shows a schematic depicting the proposed SOLAR projection system. The installation process is shown in Fig. 3. SOLAR system comprises of a dome that houses Digitairum's hemispherical (180^o FOV) high resolution (1200 px. diameter) high frame rate projection system. The projection system is paired with Phasespace's unique camera system that can acquire high resolution imagery at 100 fps. Vision camera also enables 16 64×64 regions of interest (ROIs) with programmable image space positions for recording at upto 3000 fps. This vision camera provides a representative imaging system that can emulate a variety of digital imaging sensors. A prototype system currently operational at PIs' laboratory was used to form the core elements of the SOLAR projection system. **DURIP funds were utilized to procure the graphics engine and display systems**. The funds greatly accelerated the development of the SOLAR emulation system laboratory and directly contribute

Key Milestones: A couple of key milestones in the establishment of the SOLAR system are listed below.

- **August 2016:** The SOLAR system was commissioned to existence as a university facility. Preliminary demonstration of 3D geometry estimation algorithms was carried out. Primary demonstrations included the projection of a start field and the visual identification of stars.
- **December 2016:** The SOLAR system was demonstrated as an education and outreach tool for Buffalo area high school students.

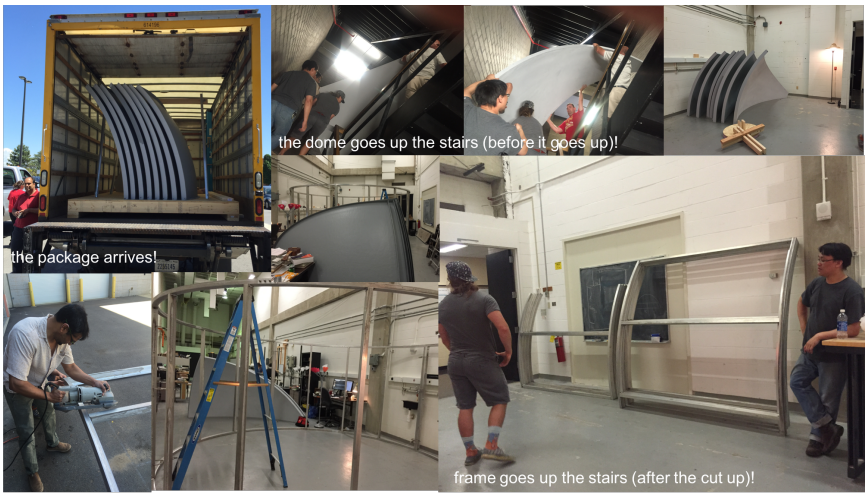


Figure 3: SOLAR system installation process

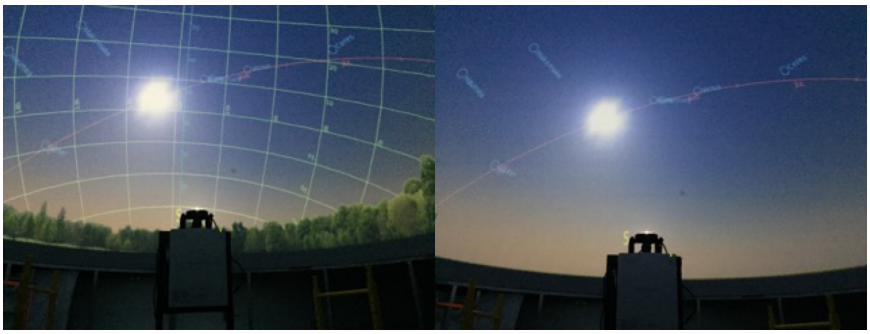


Figure 4: Images of the SOLAR system daytime simulator. Stars, planets and satellites are shown with the labels. Right side view shows the same scene without the foliage cover.

5 Enhancing UB's Ability to Educate Future Scientists and Engineers In Disciplines Important to DoD Mission

The capabilities of the DURIP sponsored SOLAR systems have significantly impacted the research programs of 5 of our faculty members within the Mechanical and Aerospace Engineering department at the University at Buffalo. This will further enhance the research of about 15 graduate students over all and 20 undergraduate student researchers. We have several fellowship and scholarship students among them, representing the cream of our undergraduate and graduate programs across disciplines.

Mr. Eamonn Moyer is an extra-ordinary graduate students who has participated in the AFRL summer student fellowship program and has been working on the development of next generation orbit determination systems for RSO tracking and characterization. Mr. Moyer has developed excellent working relationship with his Air Force mentor Dr. Ryan Weisman and we are looking forward to his next summer internship to achieve progress on projects of mutual interest.

With regards to undergraduate research, Prof. Majji and Prof. Singla currently teach a special class on the design and development of UAVs, tracking systems and computational vision. Prof. Majji is currently supervising two honors students for the development of next generation computational vision algortihms and their parallel implementations. The students involved in this course are also participating in the AIAA student competition to design, build and fly UAVs and in the SEDS programs and competitions.

AFRL/UB Educational Partnership Agreement The University at Buffalo recently signed an Educational Partnership Agreement (EPA) with AFRLs Directed Energy and Space Vehicles Directorates. The objective of this Agreement is to involve the Educational Institute in AFRL research as part of the Advanced Sciences and Technology Research Institute for Astrodynamics (ASTRIA), as well as to form a collaborative research environment, between AFRL, other universities participating in ASTRIA, and the University of Buffalo. Under this Agreement a cooperation exists between UB and AFRL for developing a program under which students may be given academic credit for work on defense laboratory research projects. This is especially important since, historically, several students from UB, under the advisement of the investigators, have participated in the Space Scholars Program at various AFRL locations. The PIs plan to have students continue to apply to this program, using various aspects of the proposed infrastructure for projects. For example, students under this program can help enhance baseline simulations and further test the developed algorithms. This program and EPA further have the benefit of allowing direct access to AFRL engineers and researchers.

Nationally unique SOLAR projection system developed at UB using DURIP funds and associated experimental research work involved in the initial setup and subsequent operations has greatly enhanced the learning experience of the motivated young researchers.